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# **Thermal Volumetric Analysis (TVA): A New Test Method of the Kinetics of Gas Emissions from Moulding Sands and Protective Coatings Heated by Liquid Alloy**

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Additional information is available at the end of the chapter

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## **Abstract**

Production of medium-sized and large castings is carried out in the sand moulds. The sand moulds, which components are made of moulding sand, the binder are different kinds of materials, the most common: moulding resins (furan, alkyd, phenolic, etc.). Internal surfaces of moulds, for increased thermal resistance, are usually covered by protective coatings. Liquid foundry alloys filling sand moulds produce intense heat, especially in layers adjacent to the cast. Under such conditions, the organic binders are burned or gasified. The resulting gases can penetrate the liquid causing the formation of defects such as blow-holes, pinholes, pitted skin, etc. The greater the intensity of the secretion of gases and the greater their volume (number), the more likely defects are created in castings. An important quality criterion of foundry resins is their tendency to emit gas. The authors developed the new test method, which allows to monitor the kinetics of gas emissions from the moulding sand and foundry coatings as a function of time and temperature (thermal volumetric analysis (TVA)). A number of studies were made for moulding sand with organic binders. Description of the research methodology and the presentation of results are the subject of the article.

**Keywords:** thermal volumetric analysis, moulding resins, moulding sands, protective coatings

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## 1. Introduction

Heating of foundry moulds by liquid metal filling the inlet system and mould cavity causes often heating of the successive - deeper and deeper situated - layers of the mould, to a very high temperature. In case of cast steel, a temperature of layers adjacent to the casting surface often exceeds  $1000^{\circ}\text{C}$ . In case of other alloys, heating is also very intensive; however, such a high temperature is not reached. A part of components of moulding and core sands and protective coatings, applied in the casting technology, undergoes gasification (burning or distillation). Gaseous products heated to high temperatures constitute an additional volume of gases, apart from the heated air. These gases should be removed from the mould cavity before it will be filled with metal. When they are not completely removed the gas pressure increase is observed in the mould cavity and in moulding (core) sand layers adjacent to the mould cavity. This often causes the penetration of gases into liquid and solidifying metal, which leads to casting surface defects classified as originated from gases. They are in a form of pinholes, blow-holes (internal or external), or shrinkage gaseous porosity. Examples of castings with surface defects are shown in **Figures 1–5**.

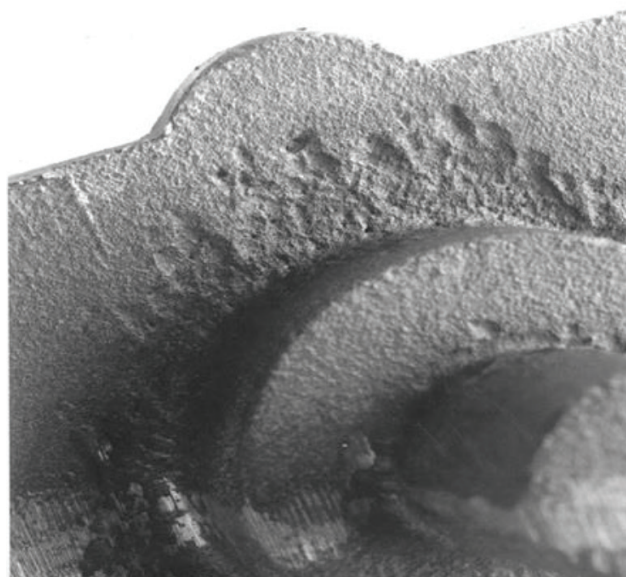
A trend of formation of this group of defects depends on several factors, but nearly always grows with an increasing gasification of moulding sands and protective coatings. The gasification is understood as a tendency of the material to form gases when it is heated. Therefore, investigations of the moulding sands gasification, understood as the amount of gases emitted by the mass unit of the material heated to app.  $1000^{\circ}\text{C}$  are often performed. The total amount of gases emitted from the moulding sand is important and has an essential influence on forming the described defects. However, the instantaneous values of gas pressures-at the metal and mould boundary-decide whether gaseous defects (shown in **Figures 1–5**) will appear. The higher is the gas pressure in the mould, during the initial phase of alloy solidification,



**Figure 1.** Iron casting with visible blow-holes on the surface, produced in the mould of wet bentonite moulding sand high-pressure technology.



**Figure 2.** Pump body casting of Al-Si alloy with visible blow-holes on the surface, produced in the sand mould - hand moulding technology.



**Figure 3.** Casting of spheroidal cast iron with the visible defect of the gaseous origin, called pitted skin, produced in the wet bentonite mould - machine moulding technology [1].



**Figure 4.** High-dimensional iron casting with visible gaseous defects on the surface, produced in the sand mould-hand moulding technology with the application of moulding sand with furan resin.





**Figure 5.** Casting of Al-Si alloy with visible blow-holes on the surface, produced in the metal mould-low-pressure casting technology.

the more probable is the defect formation. Thus, in assessing the gasification of materials applied in the moulding sand technology, there is a necessity of determining the gas emission kinetics in relation to the heating time and-even better-as the function of the instantaneous temperature at which they evolve.

The results of the gas emission investigations realised according to the new concept and with the application of the new measuring method, which allows for the parallel measuring of gas volumes in the time unit in relation to the instantaneous temperature at which the process is performed, are presented in this chapter.

### 1.1. Analysis of the problem and the research stand construction

Evolutions of gases from heated materials are physical processes related to the decomposition of components, their distillation or burning. These processes are accompanied by the sample mass loss and thermal effect (emission or absorption of thermal energy), leading to the instantaneous temperature increase or decrease. For investigating the described processes the thermogravimetry (TG) is applied, while when the mass change rates of heated samples are tested the derivative thermogravimetry (DTG) is used. The TG curve constitutes the function expressing changes of the sample mass ( $\Delta m$ ) in dependence of time (t) or temperature (T) [2]:

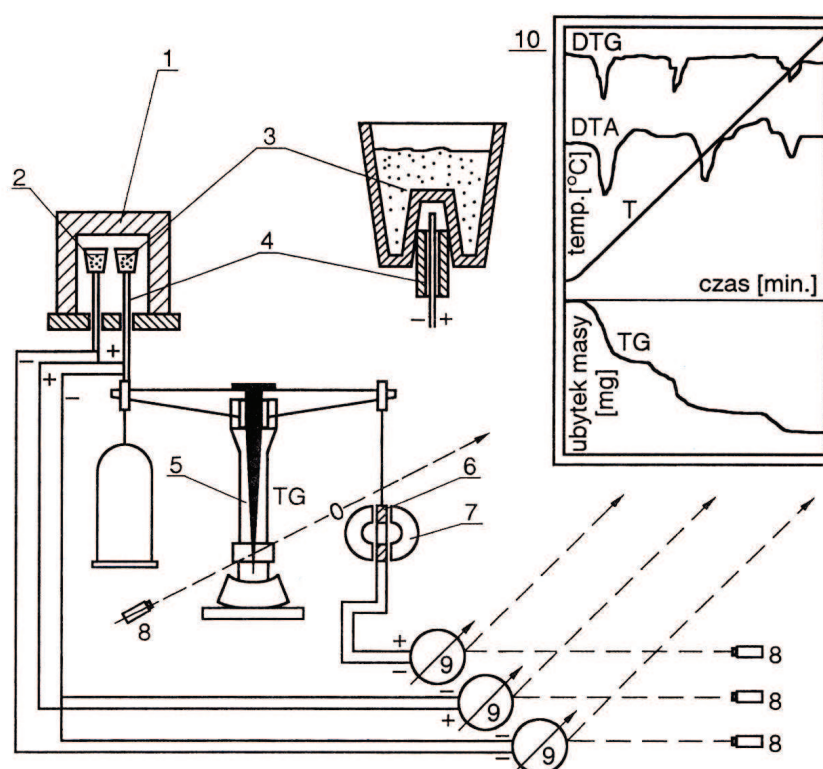
$$\Delta m = f(t) \rightarrow f(T) \rightarrow TG \quad (1)$$

The first derivative of this function versus time, expresses the mass change rate:

$$\frac{d(m)}{d(t)} = f'(t) \rightarrow f'(T) \rightarrow DTG \quad (2)$$

The DTG curve is characterised by the maximum and minimum peaks, occurring at the determined temperature values. In these points, the process rates are the highest. Devices called derivatographs are simultaneously used for recording the TG curves and thermal analysis (DTA) of the tested material. The schematic presentation of such device is shown in **Figure 6**.

The analysis of the mass changes kinetics of heated materials, applied in the mould casting technology, is not sufficient for assessing their technological suitability. The analysis of the



**Figure 6.** Schematic presentation of the derivatograph: 1 - furnace, 2 - crucible with the standard material, 3 - crucible with the tested material, 4 - Thermocouples, 5 - Scale, 6 - Induction coil, 7 - Magnet, 8 - Lamp, 9 - Galvanometer, 10 - Thermobalance [2].

amount and kinetics of evolved gases, related to the sample mass change, is also necessary. No simple quantitative relationship exists between the kinetics of the evolution of gases and the kinetics of mass changes of heated materials undergoing a decomposition (burning). It is not possible to calculate the volume of gases evolved during heating, from the mass changes of the material, which was thermally decomposed.

The authors of the hereby paper developed the investigation method of the thermal decomposition of materials in which measurements of instantaneous amounts of gases evolved from the sample in the heating process, instead of the instantaneous sample mass changes, are performed. The temperature of the tested material sample is measured simultaneously. In analogy to the TG this new investigation method was named thermal volumetric analysis (TVA) – investigations of the kinetics of the evolution of gases from materials subjected to the thermal decomposition. In analogy to Eqs. (1) and (2), descriptions of the volume changes of gases generated in the thermal decomposition process of materials are of the general form of Eqs. (3) and (4).

$$\Delta V = f(t) \rightarrow f(T) \rightarrow TV \quad (3)$$

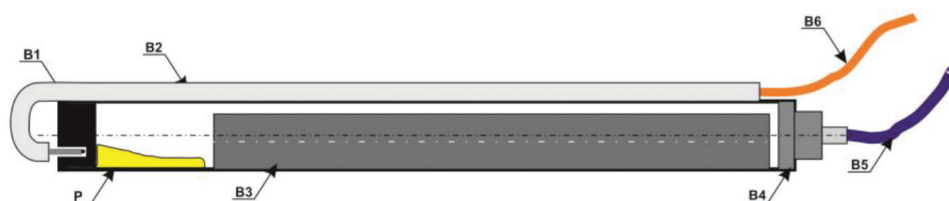
$$\frac{d(V)}{d(t)} = f'(t) \rightarrow f'(T) \rightarrow DTV \quad (4)$$

where  $\Delta V$  – volume of gases, formed as a result of the thermal decomposition (burning) of the material.

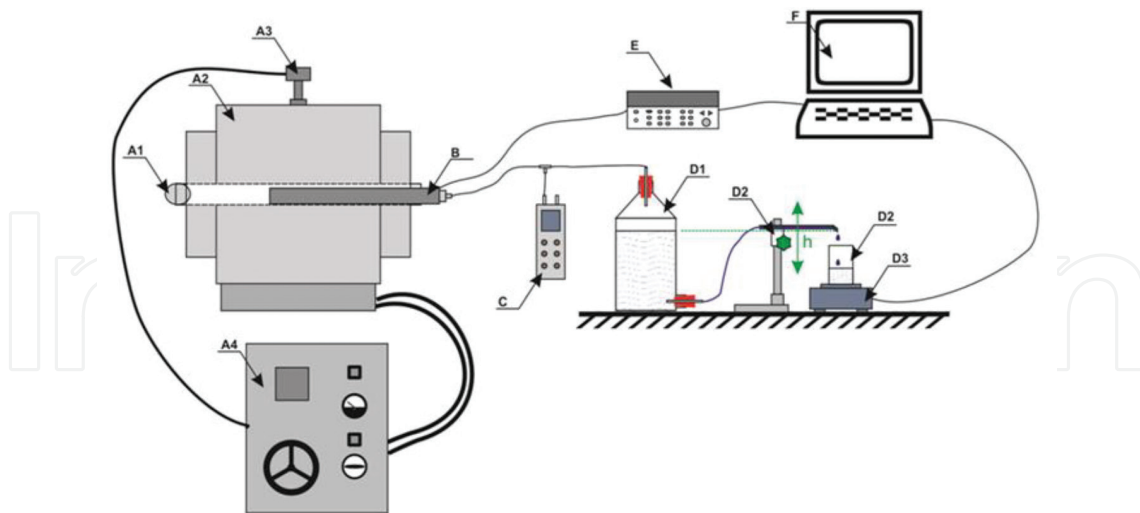
Materials for casting moulds and cores are assessed in respect of their gas forming ability. The most often, in up to now investigations, the measurements of the total volume of gases evolved from the unit mass sample [2–7] were performed, while a part of them was performed with the determination of the evolution rates in the successive time heating intervals [2, 8–11]. Thus, only dependencies that constitute the first members of Eqs. 3 and 4 were determined. It was only when the investigations described in the chapter of authors [12–16] were published that it was possible to assess the amount and rate of gases evolution in relation to a temperature. These measurements can be considered as the beginning of the derivative TVA - investigations of the kinetics of the evolution of gases from casting materials as the heating temperature function (TV). In a similar fashion as in the TG, where the most important structure element is the moulding sand probe (crucible) equipped with thermocouple (item 3 in **Figure 6**), in the thermal volumetric method the most important element of the research stand is the test probe equipped with the temperature sensor (B2) shown in **Figure 7**.

The test probe (B) in which the sample of the tested moulding sand is placed, was designed and built as unilaterally closed measuring flask of a pipe shape. To increase its resistance to thermal shocks the test probe was made of heat-resistant steel. On the other side, the test probe was equipped with a sealed valve (**Figure 7B4**). This closing valve allows for directing the gas, evolving from the sample to the measuring system. The same valve, after being disconnected from the probe (pipe), allows for the analysed moulding sand replacement (P). After performing the measurement the test probe is emptied of the tested (heated) moulding sand and purified from its remains. To reduce the test probe inner space filled with air, an insert is placed inside it (**Figure 7B3**). On the outer surface of the test probe, the pipe (B2) - guide bar - with ceramic insulators inside was placed. In these insulators, the thermocouple conduits of the 'S' type (Pt–PtRh10) (B1) were interlaced. A measuring junction of the thermocouple is placed in the zone where is the tested moulding sand sample (P). Such solution ensures an accurate and continuous temperature control of this moulding sand (P). The thermocouple conduits being at the end of the test probe were connected to the compensation conduit (B6) and to the temperature recorder.

The schematic presentation of the new stand for testing the gas evolution kinetics and for assessing gas generations of moulding sands-within TVA is provided in **Figure 8**. The test probe with the tested moulding sand (B) is introduced into the tubular style furnace PSR-1 (**Figure 8A2**) with a temperature controlled by means of a thermocouple (A3) as well as the



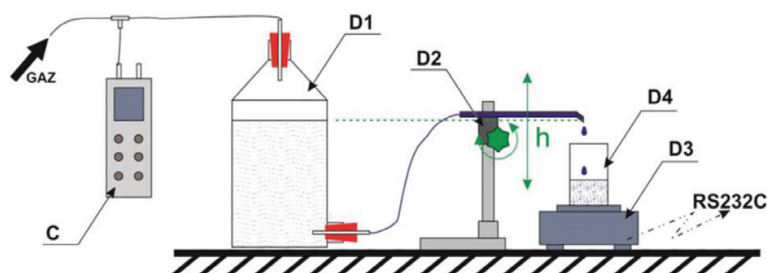
**Figure 7.** Structure of the measuring sensor (B) for the thermal volumetric investigations [12].



**Figure 8.** Schematic presentation of the laboratory stand for testing the gases evolutions kinetics and for assessing gas generations of moulding and core sands [12].

power supply and digital regulator (A4) systems. The back side of the furnace operating pipe is closed by thermo-insulating wool (A1) to limit temperature drops caused by the air flow. The air filling the cold test probe (increasing its volume as a result of heating), as well as the gas, originated from the decomposition of the tested moulding sand binder are directed-via a complex of conductors (B5)-to the system measuring their volume. The system comprises a three-way pipe distributing gas to the low-pressure meter (**Figure 9C**) and to the glass container with water (D1).

In the bottom part of the vessel with water, there is a drain, closed with a plug with a drain pipe. Gas originated from the thermal decomposition of the tested material (from the test probe **Figure 7**) is introduced via the top valve. This gas flowing into vessel D1 pushes out water from it in such volume as the gas itself occupies in the vessel. Water flowing out via the bottom valve of the vessel is first directed, by a rubber hose, to the pressure 'controller' (hydrostatic pressure) of the stand (D2) and then to the outlet zone of the pipe. It flows out from the pipe in a form of individual drops with the intensity corresponding to the gas evolution rate.



**Figure 9.** Schematic presentation of the measuring section of the gas evolving from the heated sample of the tested material [12].



Under the outlet zone of the pipe, the vessel (D4) was placed on the tensometric laboratory scale, equipped with the electronic system for the data collection and transmission to the computer. The thermocouple placed in the test probe (**Figure 7B**) is connected to the computer via the recorder Agilent 34970A (**Figure 8E**). During the measurements, the data concerning the temperature and volume of gases evolving at a particular time are gathered. Due to the fact that the water specific density equals  $1 \text{ g/cm}^3$ , the number of grams of water pushed out by the gas flowing into the vessel corresponds to its volume, which facilitates the measurement-calculation procedure.

*Measurement method:* The test probe filled with the tested material sample (e.g., moulding sand) is introduced into the furnace heated to a predefined temperature. The sample is weighed by means of the laboratory scale, with an accuracy of up to 0.01 g. The sample quantity is selected in a way assuring uniform heating in the whole volume, namely, it cannot be too large. On the other side, it should not be too small because small amounts of evolved gases make difficult their accurate measurements. At the determined measuring accuracy of devices (tensometric scale), measuring of small values (water pushed out from the vessel) are burdened with a higher relative error.

A thin layer of the moulding sand sample assures fast heating of its total volume and simultaneous gasification (burning) in the entire volume of the tested material. The weighted portion of the moulding sand is put into a clean test probe, and then a roller (B3) is inserted to reduce a 'dead volume' of the measuring system (test probe). After connecting the pipes, the water level in the vessel and outflow are equalised-the location of a drain pipe outlet. After water levelling the manometer – shows 0 mm of the water column. When the pressures are equalised the software recording the volume of water pushed out from the vessel and recording the temperature of the heated moulding sand sample is activated. The gas source constitutes the tested sample undergoing a partial gasification. When the test probe is heated the gas volume in it increases, which while flowing out to the vessel with water induces the commencement of water flowing out. At the same time in the 'on-line' mode, the quantity of outflowing water as well as the temperature of the heated moulding sand is recorded.

The gathered data are then subjected to treatment and the results are the most often presented in forms of diagrams.

*Test probe calibration:* the test probe volume in the described version equals app.  $40 \text{ cm}^3$ . When the test probe with the tested moulding sand is heated two processes simultaneously occur: increasing - due to heating - of the air volume filling the probe and the gas evolution from the tested material (e.g., moulding sand), which is subjected to distillation, burning, etc. The measurement of the total gas volume pushed out from the container provides the erroneous gasification value of the tested material. It could be called either *the total gasification or apparent gasification*. The total volume of gases flowing out from the container depends on the proportion between the working volume of the test probe and the moulding sand sample volume (weight). The higher working volume of the test probe the more 'erroneous' is the picture of the real gasification of the moulding sand.

In order to make possible the determination of the real amount of gases formed due to the moulding sand decomposition, it is necessary to determine the volume increase of the air

heated to the selected temperature in the test probe. This measurement can be called the test probe 'calibration' since it is based on recording the increasing gas (air) volume during heating the test probe to the selected temperature. To perform the measurement of the real gas evolution from the tested moulding sand sample the calibration results should be subtracted from the recorded amounts of gases evolving from the sample.

The obtained results should be divided by the amount of the tested moulding sand. Then the achieved result will be the quantity of gases emitted by 1 g of the moulding sand at the given temperature. In case of materials consisted of the matrix (which is not decomposed) and the binder, it is possible to recalculate the results into the weight fraction of the binder itself. For this purpose, the moulding sand composition and the binder percentage fraction should be known. In such case it is possible to refer to the specific gas evolution, it means to 1 g of the binder contained in the moulding sand (not to 1 g of the moulding sand).

## 2. Thermal volumetric analysis applied for testing the materials used in the casting moulds technology

### 2.1. Kinetics of gases evolutions from core sands

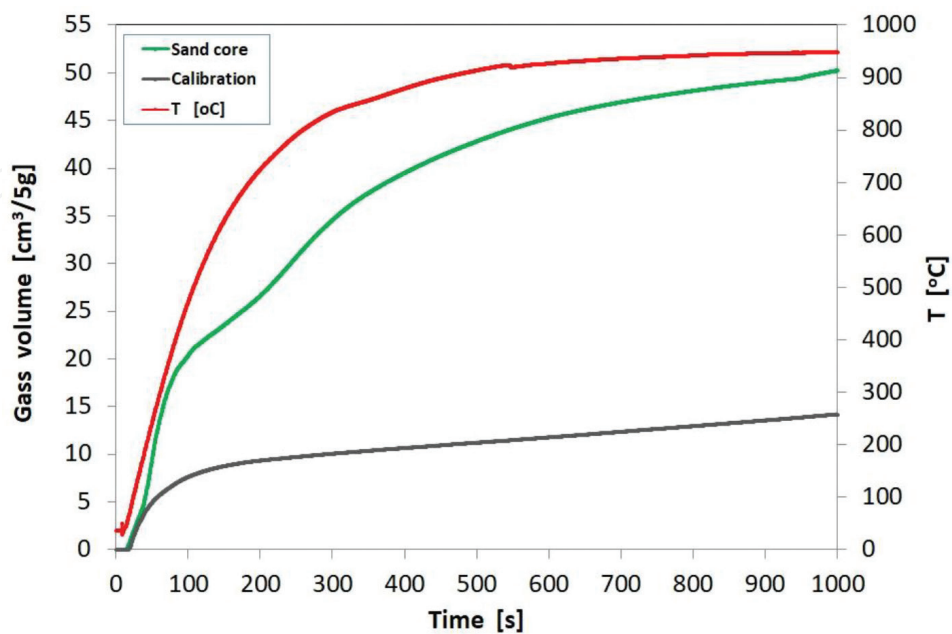
A lot of castings produced in sand or metal moulds require applications of cores for the reproduction of internal shapes of castings. Due to the fact that casting cores are poured with metal nearly from all sides, their tendency for the evolution of gases is very important since very often these gases are retained in casting walls, forming defects. Especially in such cases, a low gas generation tendency of core sands is very important. The example of such casting can be the element of a bathroom battery. The half of the metal mould with the inserted sand core is shown in **Figure 10**. In this mould-after joining its two halves-the casting of the element of the domestic plumbing fittings, the so-called spout, will be made of brass. The sand core is produced in the hot box technology in which the core sand binders are thermohardened resins, the most often phenol or phenol-urea resins.

Investigations applying the new method thermal volumetry analysis were performed to assess the quality of moulding sands used for cores, from the point of view of their tendency for the evolution of gases during heating by liquid metal. The results of these tests are presented in **Figures 11–14**. Cores were produced of sands in which thermohardened resin, classified to the phenol group, was used. The core sand contained approximately 2.0% of phenol-urea resin, Resistal HB AT 12. Tests of gas evolution rates were carried out on the research stand, which scheme is shown in **Figures 8 and 9**. As it was already indicated, during investigations of the moulding sand thermal decomposition and the evolution of gases accompanying this process-performed by the new method-the continuous measurements of the sample temperature and the volume of gases generated by the heated moulding sand were carried out. In addition, the test probe calibration described above was performed. The obtained results are presented in **Figure 11**. On their bases, according to general Eq. 4, the gases evolution rates as the heating time function (**Figure 12**) and as the material (in this case

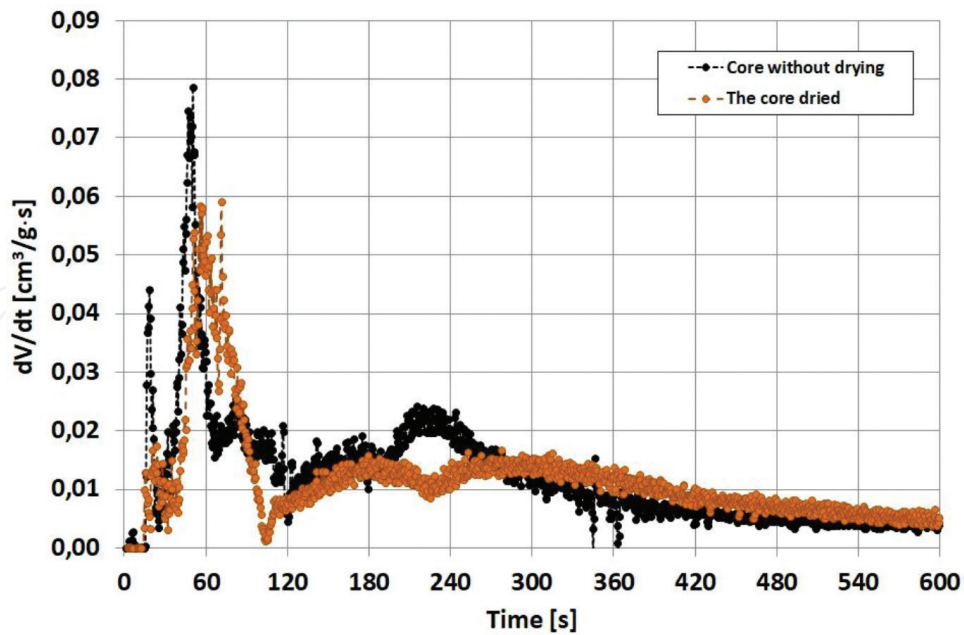
the core sand) sample TV (**Figure 13**) are determined. Kinetics of the gases evolution shown in **Figure 12** indicates that this process is intensive already in the first minute of heating. The sand without additional drying emits much more gases and much earlier, which favours the gaseous defects formation.



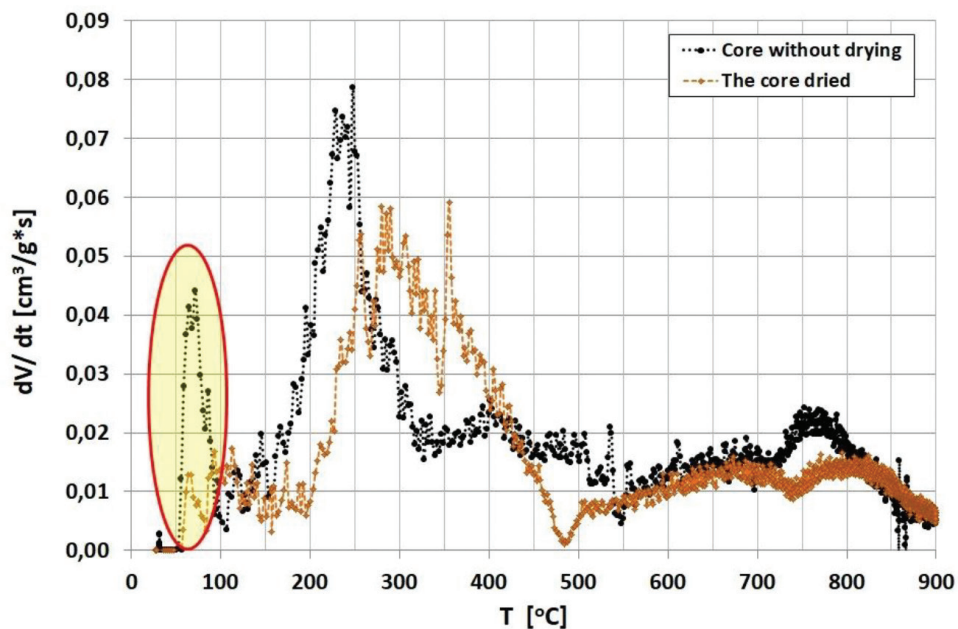
**Figure 10.** Metal mould (half of the mould) with the sand core.



**Figure 11.** Changes of the sample temperature and of the volume of gases, recorded during the test probe calibration and core sand measurements (without drying) for the hot box technology.



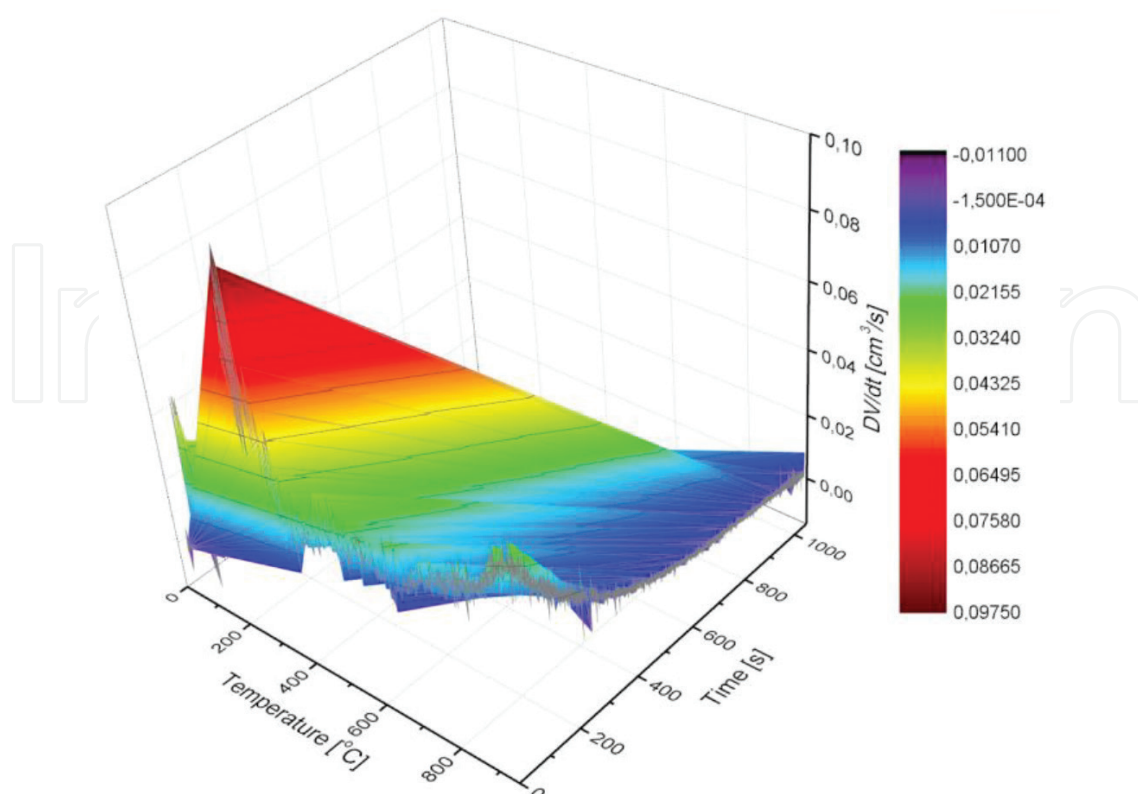
**Figure 12.** Kinetics of the evolution of gases from the core sand heated to app. 950°C.



**Figure 13.** Intensity of the evolutions of gases from the heated core sand, applied in the hot box technology, as the heating TV.

Courses of the evolution of gases from cores without the previous drying and after additional drying are compared in **Figure 13**. The core was dried for 1 h at a temperature of 100°C. Three maxima can be separated in the courses of the evolution rates ( $(dV/dt) = f(T)$ ): the first one, when a temperature is near 100°C; the second, when the sample temperature is within 250–300°C range and the third, when the temperature is nearing approximately 800°C. Gases from the core can penetrate the casting only during the period when metal is





**Figure 14.** Intensity of gases evolutions from the core sand as the TV and the heating time function.

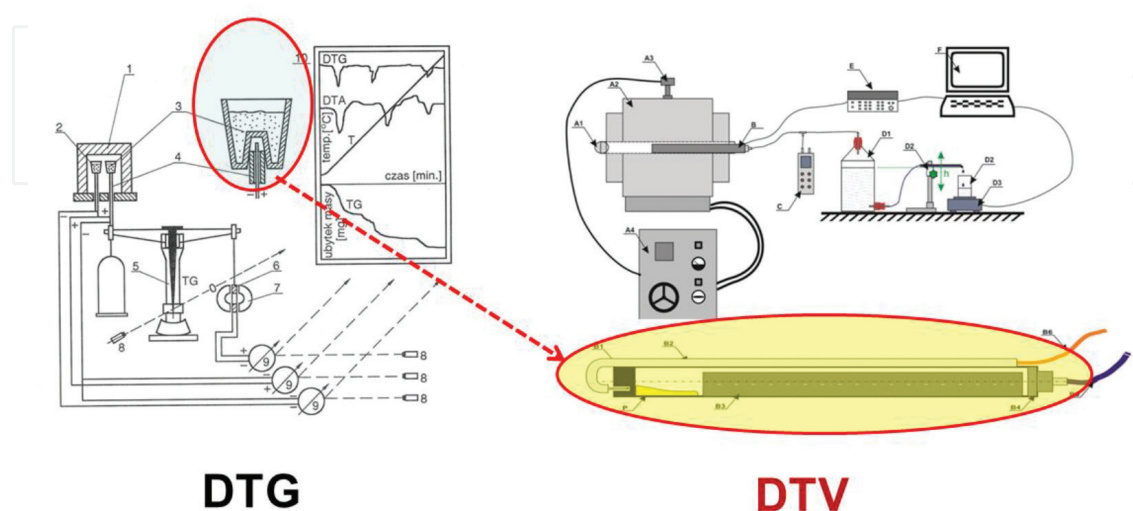
in the liquid state. In case of the casting shown in **Figure 10**, this period is no longer than app. 10 s. Therefore, for the production technology of these castings, two first peaks-seen in **Figure 13**-are important. Especially dangerous is the occurrence of the first maximum since in this period metal poured into the mould is still in the liquid state. The practical conclusion from the described example of the TVA is such: the cores produced in the hot box technology with using phenol-urea resin as a binder should be dried, to get rid of the first peak of the volume of gases seen in **Figures 12** and **13**.

The developed investigation method allows to analyse the process of evolution of gases from the selected material either as the heating time function (**Figure 12**) or as the TV (**Figure 13**). These two parameters: temperature and time cannot be physically separated since the temperature changes occur in parallel with the heating time changes. However, on the bases of the same data, the spatial picture of the gases evolution intensity from the heated material can be built in the real-time function and the real TV. The example of such approach to the description of the gases evolution from the tested core sand, for which partial dependencies are shown in **Figures 12** and **13**, is presented in **Figure 14**. It can be noticed, that the intensive evolution occurs at the very beginning of the heating process and at a relatively low-temperature. At further heating, regardless of the higher temperature, the intensity of the gases evolution decreases. When the tested material was approaching this higher temperature a large amount of the binder (resin) was already gasified. This particular conclusion concerns only the tested core sand with the phenol-urea resin. Other materials will be forming a different picture of the gas evolution courses.

## 2.2. Kinetics of the gases emission from protective coatings

Inner surfaces of sand moulds and cores, in order to increase their thermal resistance, are often covered by various protective coatings. A potential source of gases in protective coatings is diluents (alcohols, water), which, regardless of drying of coatings deposited on moulds, are not always completely removed. Water in coatings can occur as a diluent (free water) or as a component of material used for making the coating (e.g., bentonite) and in such case, it is the so-called bound water. To improve rheological properties of coatings various additions are often introduced (e.g., polymers), which can also be the source of gases originated during the mould heating after covering it with liquid metal. Also, metal moulds are covered by protective coatings to decrease the casting cooling rates, for the easier separation of castings from moulds and to protect the mould surface against thermal shocks. However, at the increased inclination of coatings for the gases evolution, casting surface defects can be formed (Figure 5).

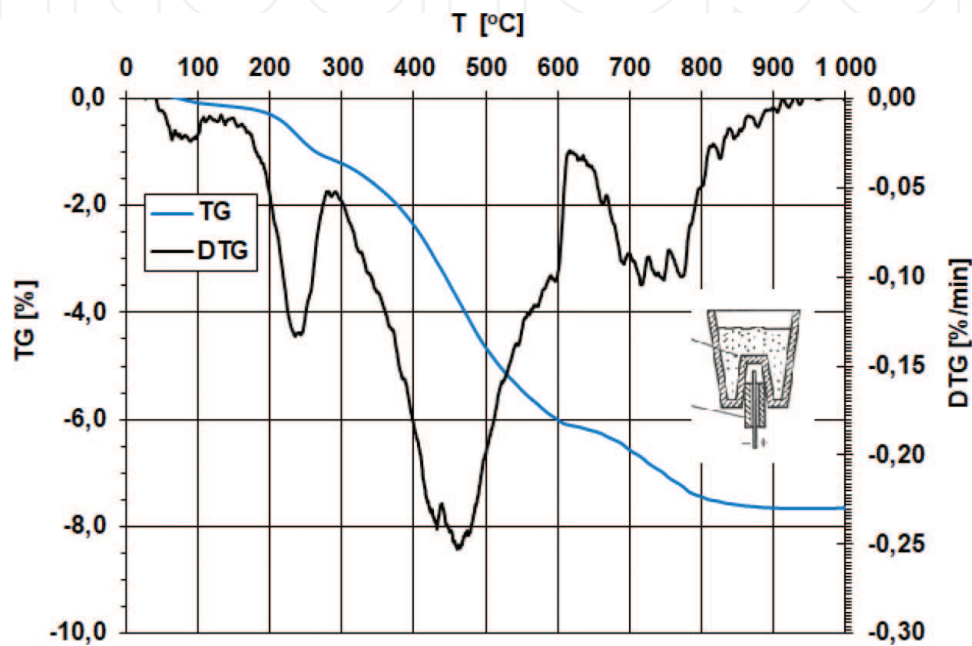
In the previous solution, the assessment of the coatings inclination to evolve gases during heating was performed on the bases of DTG investigations. Information concerning the temperature at which the heated material sample decreases its mass, due to the gasification of some of its components, was obtained from these tests. The scale of the sample mass changes could be utilised for predicting amounts of gases, by means of proportion: larger changes of the sample mass-larger volumes of gases. During the DTG tests, the heating process of the sample is performed with a constant and usually small rate. Heating of the casting moulds elements is abrupt. The research stand for the thermal volumetric tests described in the hereby paper is prepared for very fast heating of the material sample, which corresponds to the conditions occurring in casting moulds after being poured with liquid metal. To compare both methods assessing the thermal decomposition of materials, one protective coating was tested by means of the TG, DTG and TV, DTV methods. Schematic presentations of the research stands for both methods are shown in Figure 15, indicating that the main difference constitutes the construction of test probes: one is used for testing changes of the sample mass



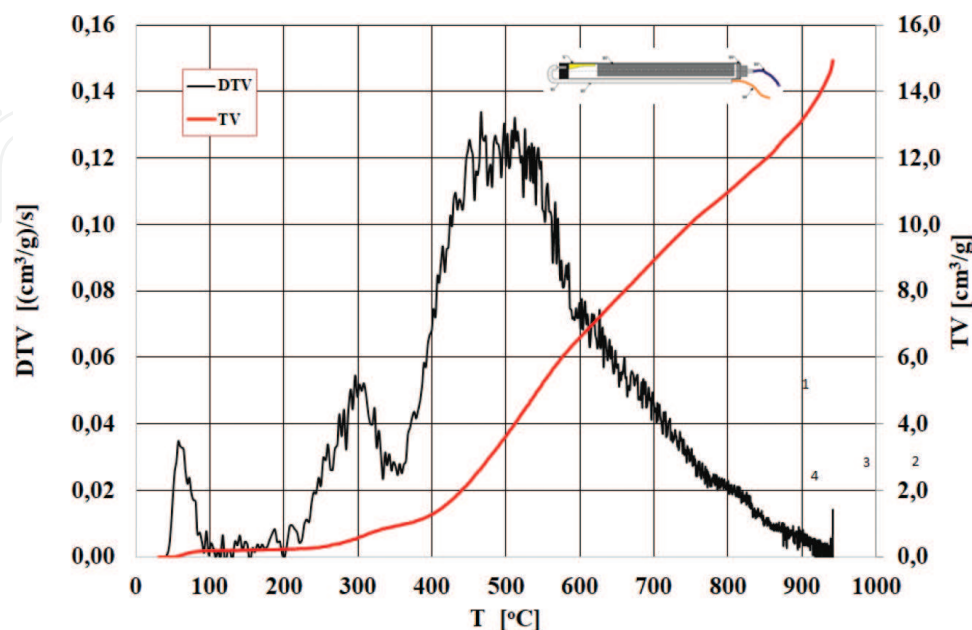
**Figure 15.** Schematic presentation of the research stands for the DTG and thermal volumetric analysis (DTV).

DTG, while the other one – for testing the volume of gases evolving from the heated material (DTV). If the heating rates were the same on both stands the diagrams of mass changes and of volume changes of gases, presented as the TV, would be very similar.

Since the situation is not like that, in order to find differences the comparable investigations of one protective coating were performed by both methods. Investigations concern the alcoholic coating, called Velvacoat GH70, applied for sand moulds and cores. The results of thermogravimetric tests (DTG) are seen in **Figure 16**, while the results of investigations of evolutions of gases and their rates (DTV) in **Figure 17**. In the qualitative approach, a



**Figure 16.** Investigation results (thermogravimetry DTG) of the alcoholic coating (Velvacoat GH70).



**Figure 17.** Investigation results (thermal volumetric analysis DTV) of the alcoholic coating (Velvacoat GH70).

significant similarity of the DTG and DTY curves can be noticed since in both cases peaks of changes of derivative values occur at similar temperature values. The first peaks occur at a temperature app. 100°C, the second at 250–300°C and the third, the highest, at temperatures 450–500°C. The fourth peak occurring in the TDG curve at temperatures 700–800°C is not clearly recorded in the TDV line. The results obtained from comparing these two methods indicate that the assessments of the thermal decomposition coincide with each other. However, the new investigation method, thermal volumetric analysis, provides additional important information on materials, essential for several technological production processes. The intensive evolution of gases from heated materials renders difficult the technologies of casting production regardless of being realised in sand, ceramic or metal moulds.

The thermal volumetric method was also applied in investigations of other protective coatings used for covering sand cores. During the preparation of coatings, they are usually diluted with alcohol, which vapourises after coatings are deposited on the core surface. To get rid of the diluent, before the gas evolution measurements, coatings were dried for 2 h at a temperature of 130°C. After drying the coating was crushed to powder. Four coatings of symbolic designations were tested. These coatings - after drying - are presented in **Figure 18**.

The gases evolution courses, during heating, are presented in **Figures 19** and **20**. The gas evolution courses as the TV are shown in **Figure 19**. It can be noticed, that peaks occur in two temperature ranges: 250–350°C and 550–600°C. Up to the present convictions, that only not properly dried coatings can be the source of gases in casting moulds after they were poured with liquid metal, are not confirmed. All tested coatings, regardless of being dried, emit significant amounts of gases (**Figure 19**).

From the point of view of the technological suitability and maintaining a low risk of casting defects forming, the coatings characterised by the lowest gas emission should be selected. The second recommended feature is shifting of peaks of the most intensive emissions to higher temperature values. In such case, it is more probable that metal will solidify earlier than large amounts of gases from the coating will appear in the mould. Out of the compared coatings the lowest inclination for evolving of gases has the coating marked with BC3 symbol. The result of these investigations was positively verified in one of the Polish foundry plants. The developed new method of investigating the materials inclination for emissions of gases when they are heated (thermal volumetric analysis DTV), becomes the good tool for assessing the technological suitability of several materials, including protective coatings.



**Figure 18.** Alcoholic coatings, after 2 h of drying at 130°C.



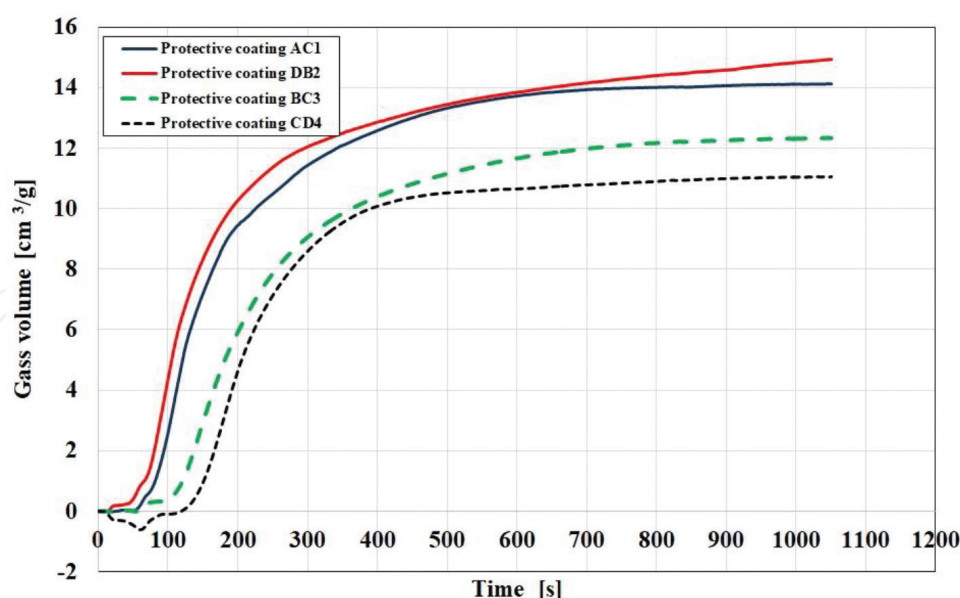


Figure 19. Gases evolution courses from alcoholic protective coatings applied for sand moulds and cores.

### 2.3. Kinetics of gases evolutions from expanded polystyrene

Currently the full mould technology in several versions is more often applied in the foundry practice. This technology essence comes down to using casting patterns made of expanded polystyrene. The pattern is expendable and after making the mould remains in it. The poured metal causes its gasification and by taking its place obtains the shape of the casting. The most important in this technology is the amount of gases originated from the casting pattern gasification since it decides on the possibility of producing castings without defects. Equally important parameter, possibly even the most important one, is the intensity of the evolution of gases during pouring. In one technology the polystyrene pattern is covered by the coating layer, and after drying the whole is placed in the box with the dry sand. Gases from the polystyrene gasification process have to permeate at first through the protective coating and then through the sand, to be finally outside the mould. Too slow flowing out of gases from the inside of the mould can be the reason of the liquid metal gasification, changes of its chemical composition and the porosity formation [7]. Within the project of assessing materials for patterns for the full mould technology the kinetics of gases evolutions from three kinds of gasified materials was investigated. Investigations comprised: polystyrene of a white colour ( $\rho_o = 23.2 \text{ kg/m}^3$ ), blue ( $\rho_o = 39.4 \text{ kg/m}^3$ ) and extruded polystyrene Austrotherm XPS TOP 50 SF ( $\rho_o = 47.8 \text{ kg/m}^3$ ) of a pink colour.

The results of gas evolutions of the tested polystyrenes are presented in **Figures 21–24**. The source material of the performed measurements is the record of temperature changes of the heated polystyrene sample and the record of the amount of gases emitted by the sample in successive seconds of its heating. Such record is presented in **Figure 21**. The amount of the evolved gas can be referred either to the sample mass (1 g) or to its volume (1 cm<sup>3</sup>). Referring to the material volume is more justified in the foundry practice. In such approach, in relation to the volume unit, the smallest amounts of gases emits white polystyrene, slightly more blue

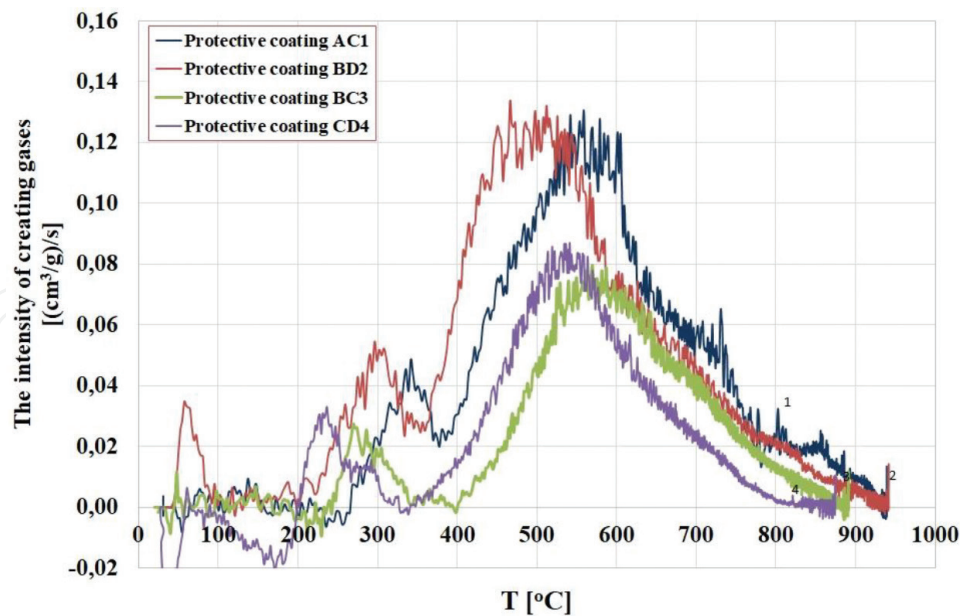


Figure 20. Intensity of gases evolution (DTV) from protective coatings applied for sand moulds and cores.

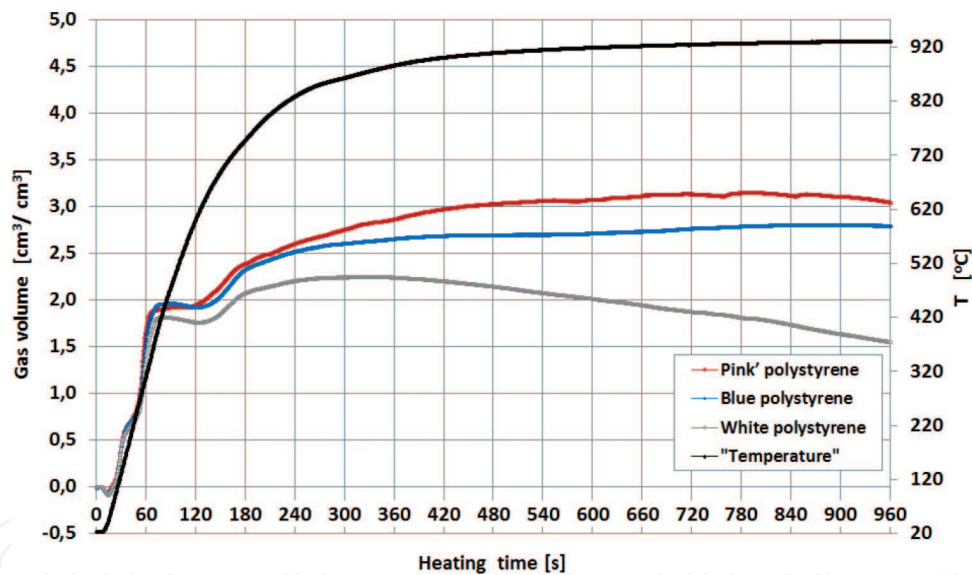
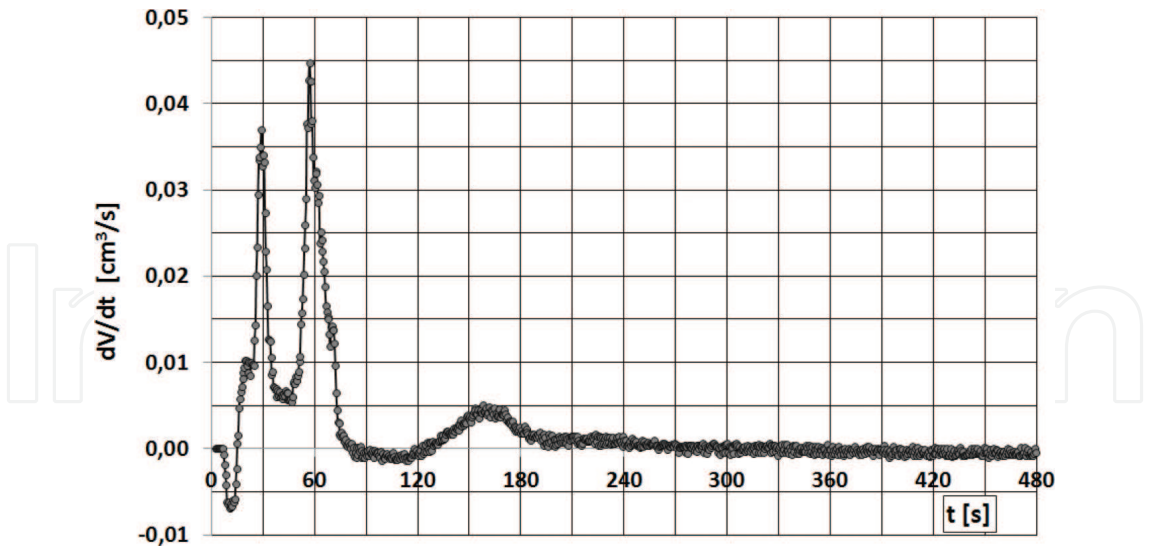
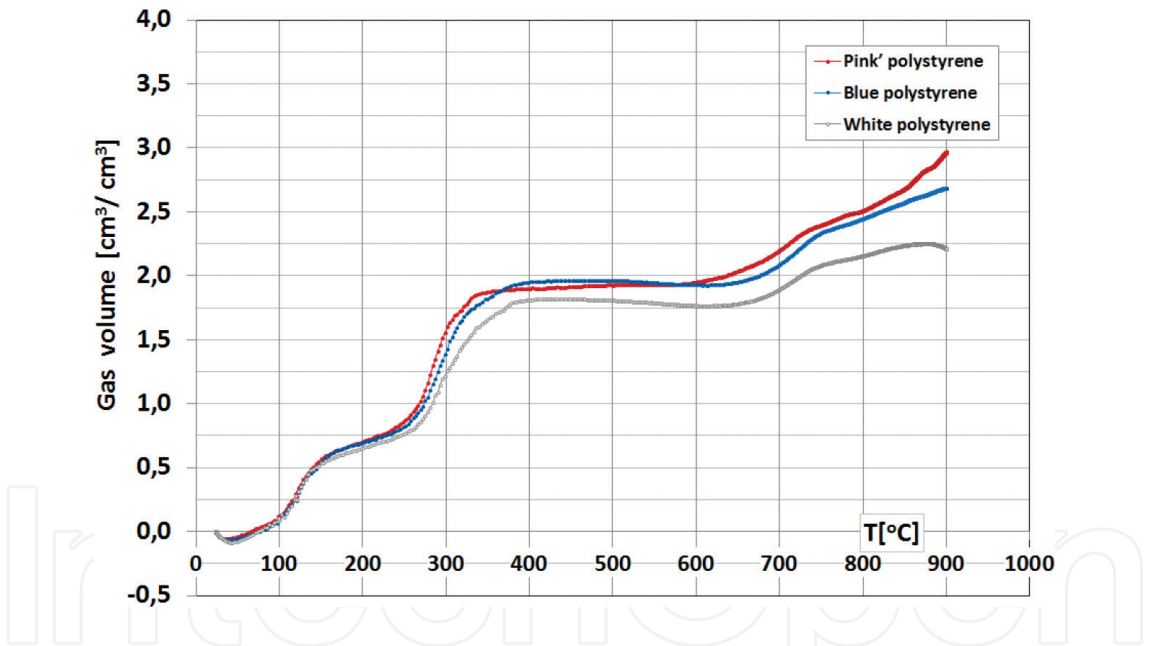


Figure 21. The course of heating of the expanded polystyrene samples and of the emission of gases.

polystyrene, while the highest amounts the 'pink' one. Differences reach more than 20% of the volume. Each of these polystyrenes has a different density, which is related to the amount of emitted gases. Apart from the amount the important factor is the rate of the gasification process of polystyrene. For 'white polystyrene' amounts of gases emitted in successive seconds of heating are shown in **Figure 22**. The remaining materials have similar courses of the emission of gases. Three, different sizes, peaks of the gas evolution intensity can be singled out in the gasification process. Two first peaks are larger and occur one after another in a short time (after 30 and 60s), and the third one, significantly smaller, occurs much later, after approximately 160 s.

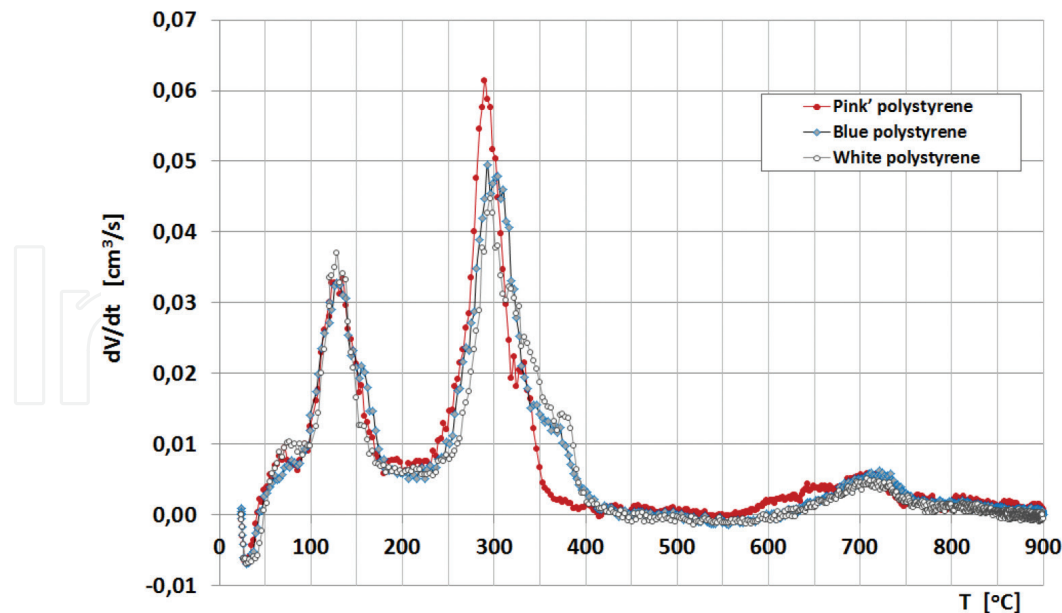


**Figure 22.** Kinetics of the emission of gases from expanded polystyrene (white) during its gasification (heating of 1 cm<sup>3</sup> of polystyrene).



**Figure 23.** Gases evolutions during heating the polystyrene samples, the influence of a temperature on the amount of gases emitted from 1 cm<sup>3</sup> of polystyrene.

Assignments of temperatures, at which successive changes of the gases evolutions rates occur, are visible in **Figures 23 and 24**. Three temperature values, at which the acceleration of the gas emission process is quite visible, are seen in **Figure 23**. It can be seen more accurately in **Figure 24**. Applying the developed thermal volumetric method, derivatives  $dV/dt$  were determined and the temperature values were assigned to them (DTV). The first maximum of the gases emission rate occurs at a temperature of app. 130–140°C, the second - at a temperature of app. 300°C, while the third, significantly smaller, at a temperature from the range: 700–750°C.



**Figure 24.** Influence of the temperature of polystyrene heating on the gases emission kinetics.

These are the temperature ranges and values at which the gas pressure in the mould rapidly increases and the mould (especially its coating) must be able to carry away these fast increasing amounts of gases. The gasification process of polystyrene is the most intensive at a temperature of app. 300°C. When comparing kinetics of gas evolutions from the expanded polystyrene (**Figure 24**) and from resin (**Figure 13**) their similarity can be noticed. This similarity is due to the fact that these both materials are organic compounds.

### 3. Conclusions

The presented new method of investigating the kinetics of gases evolutions from materials subjected to heating, called the thermal volumetric analysis (DTV), constitutes the supplement of the up to now applied thermo-gravimetric (DTG) method of testing the kinetics of the sample mass changes of the heated materials. As it was revealed in investigations both methods are compatible with each other, the thermo-gravimetry allows to determine temperature values at which the thermal decomposition and gasification of the material components occur, while the thermal volumetric analysis allows to determine the intensity of the emission of gases at the same temperature values. Tests carried out for several materials and plastics applied in casting technologies confirmed the high suitability of this method, and the obtained results can constitute the base for assessing the suitability of the given material for the casting process.

This new investigation method is currently at the stage of testing prototype solutions in construction of the research stand and is, within this zone, improved. The range of the future applications of the thermal volumetric analysis should not be narrowed to materials used in foundry practice only. The problem of the intensive emission of gases from heated materials occurs in several processes and often complicates various technologies.



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